CIBTech Journal of Zoology ISSN: 2319–3883
An Online International Journal, Available at http://www.cibtech.org/cjz.htm
2025 Vol.14, pp.299-313/Sai and Sumanth
Research Article

IMPLICATIONS OF BETTER MANAGEMENT PRACTICES (BMPs) ON GROWTH PERFORMANCE, SURVIVAL RATES AND FEED CONVERSION RATIO IN *LITOPENAEUS VANNAMEI* CULTURE WITH SPECIAL REFERENCE TO CLIMATE CHANGE

Sai Vamsi Ratti* and Sumanth Kumar Kunda
Department of Zoology & Aquaculture, Acharya Nagarjuna University, Nagarjuna Nagar-522510, Andhra Pradesh, India.
**Author for Correspondence: sv26919@gmail.com*

ABSTRACT
Globally shrimp culture is among the most rapidly expanding food-producing industries, but the yield is becoming more and more affected by global climate change and the environmental stressors. The study quantifies the implications of regulated. Better management Practices (BMPs) on growth performance, survivability, feed conversion efficiency and comprehensive production of *Litopenaeus vannamei* cultured in pre and post-monsoon seasons under semi-intensive cultivation. The four grow-out ponds (2 acres each; 25 PLm^{-2}) were observed in two full experimental cycles. Uniform BMPs, such as pond pre-stocking management, water exchange, standardized stocking densities, water quality regulation, feeding regimens, aeration and biosecurity, were mandated to control for climatic effects during seasons. Growth was measured at 15-day intervals from 30 days of culture (DOC). The growth metrics, including Average Body Weight (ABW), Daily Weight Gain (DWG), and Specific Growth Rate (SGR) did not vary significantly between seasons and were within the optimal commercial ranges in both periods. But strong seasonal variations was noted in the survival rates, total biomass and productivity rates. The statistical analysis (Welch t-tests and Mann-Whitney U tests) proved that biomass reduction under post-monsoon climatic conditions was induced by survival rather than a failed somatic growth. These statistics shows that BMPs are effective in sustaining seasonal growth performance, regulating seasonal stress impacts and contributing to reliable production across variable climatic conditions. This result shows that the resilience of *L.vannamei* under BMPs provides actionable insights for climatic-adaptive shrimp aquaculture.

Keywords: *Better Management Practices (BMPs), shrimp culture, climate change, seasonal variation, growth performance, survival rates, feed conversion ratio*

INTRODUCTION
The shrimp industry is one of the most important and booming aquaculture industries in the world, which is ranked among the top sources of national revenue for certain countries (Mansour *et al*., 2022; Mirbakhsh *et al*., 2023). Due to the continuous decline in wild catch, farmed shrimps have fulfilled the demand for the shrimp in recent years (Boyd *et al*., 2020). Countries like China, India, Thailand, America, Malaysia, Indonesia, Peru, Colombia, and Philippines have emerged as major producers (Belton *et al*., 2018; FAO, 2020: Joffre *et al*., 2019; Ul Hassan *et al*., 2021). Shrimp farming is more profitable sector than compared to agriculture sector due to its short production cycle between 100-120 days (Rao *et al*., 2021) and provides a wide range of economic benefits, food security, livelihood, and the well-being of fisherfolk, fish farmers and processors which given the high value and premium status of shrimp as a sought after food production (Macusi *et al*., 2022; Notohamijoyo, 2023).
Among farmed shrimp species, *L. vannamei* is the most dominant, economically important and highest ranking species in terms of traded seafood commodities, as well as the most widely cultivated shrimp

species globally to meet the demand (Huang *et al*., 2020; Hussain *et al*., 2020; Phan, T.C. *et al*., 2023; Ratti & Kunda, 2025; Ren *et al*., 2020: Richardson *et al*., 2021: Zhou *et al*., 2020). This species has sustained demand in both domestic and export markets (Fan & Li, 2019; UI Hassan *et al*., 2021). It gained familiarity among all other farmed shrimps due to availability of specific pathogen-free (SPF) seeds (Arisekar *et al*., 2022; Ye *et al*., 2023) wide consumer demands, ease of cultivation, rapid growth rate, (Putra *et al*., 2018), and its tender fleshness (Ayiku, 2020). In addition, it is the most lucrative commercial crustacean consumed by people globally, due to its good protein source, balanced amino acids, unsaturated fatty acids, vitamins and dietary minerals which plays a great role in human nutritional needs (Arisekar *et al*., 2022; Cornejo-Grandson *et al*., 2018: Swamy.Durai & Shamili, 2022: V. Durai *et al*., 2022; Eissa *et al*., 2022 Yassien *et al*., 2021). India, in particular, has seen tremendous growth in *L.vannamei* production, and the species contributes the majority share of national shrimp exports. During fiscal year 2023-24, frozen shrimp exports totaled 716004 MT, worth US$ 4881.27 million. The USA is the single largest importer of frozen shrimp (295571 MT), followed by China (148483 MT), the European Union (89697 MT), Southeast Asia (52254 MT), Japan (35906 MT), Middle East (2851 MT), and others (63521 MT) (MPEDA, 2024). Furthermore, India has 1.24 million ha of brackish water area spread over coastal states and Union territories. Inland fisheries have expanded in absolute terms, although its full potential has not to be realized yet (Department of Fisheries, 2025). Andhra Pradesh alone contributes for over half of India's registered shrimp farms (22634/48.9%), showing the species economic importance at both regional and national levels (CAA, 2024).

However, the increased intensification of shrimp farming has made production systems more vulnerable to environmental deterioration, water quality fluctuations and disease outbreaks. These issues are further exacerbated by climatic changes, which is anticipated to intensify by 2050 and is already exerting significant influence through increasing sea levels, temperature changes, irregular precipitation, increased storm frequency, floods, drought and cyclones (Das *et al*., 2016; Engelhard *et al*., 2022; IPCC, 2018; Zacharia *et al*., 2016). These climatic stressors have a direct impact on shrimp physiology, metabolism, and survival, which indirectly affecting pond productivity, growth performance, survival rates, water quality and overall ecosystem balance (Adhikari *et al*., 2018; Maulu *et al*.,2021).

Given these multifaceted issues, Better Management Practices (BMPs) have been recognized as critical frameworks for promoting sustainability and enhance economic viability in shrimp farming (Pashudhan Praharee 2020). BMPs were jointly developed by international organizations including FAO, NACA, World bank, WWF and UNEP (Philips & Subasinghe, 2006). BMPs include systematic criteria for site selection, pond preparation, seed quality, stocking density, feed & water management, biosecurity and responsible harvesting (Jagadeesh *et al*., 2020: Jarh *et al*., 2024). In India, extensive promotions of BMPs promoted through the national center for sustainability aquaculture (NaCSA). This considerably improved farm-level outcomes by lowering production risks and encouraging environmental stewardship (Sivaraman *et al*., 2019).

L.vannamei growth is influenced by combination of intrinsic factors such as age, sex, and physiological maturity, as well as extrinsic factors such as water quality, feed quality, stocking density and toxic metabolites (Suwoyo & Henrajat, 2021). Inadequate awareness or partial implementation of BMPs continues to be a key cause to crop failure, low growth, and mortality in many farming locations (Kumaran *et al*., 2017, 2021). In contrast, consistent adoption of scientifically designed BMPs is related with improved growth rates, enhanced feed conversion ratios, better survival, and resilient production systems (Aisyah *et al*., 2023; Haque *et al*., 2025). However, there is paucity of research done in implementing BMPs to mitigate climate change.

MATERIALS AND METHODS

Experimental site

The present study was carried out for 120 days in two culture cycles, which were examined during (2024 – 2025) in Pre- monsoon (February – May) and Post-monsoon (September – December) seasons, in four semi-intensive culture ponds (Ponds A-D), located at Alluru village, Prakasam district, Andhra Pradesh, India. Each pond having an area of 2.0 acres (8093.71 m^2/ 0.809 ha), were taken for this experiment. The depth maintained between 1.2-1.6 m. Water intake was carried out by screening at the main sluice and individual pond inlet with a double layer of fine mesh filter net 40 µm to eliminate unwanted entry of fish seed and debris. All four cultured ponds were managed under uniform BMPs, ensuring the climatic variation remained the only major source of difference between cycles.

Better Management Practices (BMPs)

Pond preparation and fertilizers

Pond preparation was carried out as per BMP guidelines (MPEDA, 2023). All the ponds were allowed to dry in the sun for nearly 30 days until the soil cracked. After complete drying, the soil surface was subjected to Ploughing and tilling. It was done two times with the gap of four days to remove the entrapped toxic gases and for enhancement of fertility of the pond bottom. After completion of this process, the ponds were filled with water within 4 days from nearby estuarine canal and top-up using motor pumps. After filling the pond, disinfection with bleaching powder ($CaOCl_3$) at the rate of 400 kg ha $^{-1}$ was carried out as a part of the biosecurity measures. Lime ($CaCO_3$) was applied to nullify the acidity of the soil, followed by bleaching application to all ponds at the rate of 200 kg ha^{-1}. It is applied to increase an overall alkalinity and hardness concentration that enhances primary productivity. Organic fertilizers like dry pond manure were distributed on the pond bottom before filling with water. Liming and Fertilization was carried out at an interval of 7 and 15 days respectively during the whole culture period.

Seed stocking

Healthy and disease free post larvae (PL) collected from Certified Private Hatchery and transported to the experiment site, in oxygenated double- covered polythene bags. They were confirmed negative for the White Spot Syndrome Virus (WSSV) and Taura Syndrome Virus (TSV) through Polymerase Chain Reaction (PCR Assay) before packing. Shrimp PL weighing 0.02g were stocked at size of 12 PL after 20:00 hrs, with stocking density of 25 m^{-2}. After obtaining the seed bags, they were acclimatized for 30 min and released to the culture pond.

Water quality management

Minimal water exchange was performed in the farms to reduce the risk of disease contamination. Only 8-15 % of water was exchanged per day. When the pond water is clear in early stages of culture a mixture of jaggery, rice bran and yeast of 25 kg+10kg+0.25 kg ha^{-1} were added to get bloom. To reduce the bloom 10 cm of top water was changed. To maintain optimal pH values (7.5 – 8.3) liming was done to increase pH whereas molasses is added to reduce the pH. After every water intake or exchange and after rains, Agrilime (100 Kg ha^{-1}) was mixed with water and applied throughout the pond. It acts as a buffering agent for water.

Feed management

A good quality commercial feed obtained from "Sandhya Marines Limited" (crude protein, CP 35-36%; crude fat, CFat-5%; crude fiber, CF-3% and moisture-11%) was given to the shrimp for 120 days of culture. During the first 30 days of culture, the shrimp were given feed number 0 and then followed by feed number 1 in the form of crumble by blind feeding. For next 30 days the shrimp were fed with 2 number crumble feed. Then along with the increase in their size, the shrimp was fed with 3 number pellet feed. The feed was broadcasted all over the pond by using boat. Two check trays were used to maintain for proper feed management. Feed was adjusted based on the expected survival and biomass. The shrimp were fed with apparent satiation four times a day (07:00am; 10:00am; 02:00pm and 5:00 pm), and the amount of feed was based on the expected growth and feed conversion rate. Feeding was reduced during periods of low DO, plankton crash, rain fall, molting, and extremes of temperature and during disease outbreaks. Check trays were installed after 10 days of stocking and monitor the feeding from 20 days. Aerators were turned off just before feeding until 2 hrs after feeding.

Aeration management

Eight paddle wheel aerators (1 HP) were provided in each grow-out pond will used to run 6 h per day initially and increased the run time (8-15 h) based upon the biomass. The use of aerators in pond has a strong influence on the maximum yield that can be achieved from the pond. Aerators were fixed 3 m away from the dyke. It was maintained 80 to 100 RPM and positioned correctly and operated efficiently to minimize pond dike erosion and suspension of pond bottom sediments. It was positioned in clockwise direction which encourages the maximum water flow within the pond adequate to concentrate waste in the centre of the pond and provide a clean feeding area.

Biosecurity management

Foot baths and wheel baths were carried out by the disinfect solution (KmnO4), which was placed at the entrance of each pond. Hand-wash stations were installed. Sampling was carried with separate sampling bottles in each pond. Farmers/workers avoided getting in to ponds unless it is very necessary. Crab fencing and bird fencing were made.

Sampling and Growth assessment

To monitor the shrimp growth, Sampling was carried out 30 days after stocking by cast netting, 20 shrimp samples randomly at different locations from each pond during 06:00–09:00 h and sampling was continued through-out the whole culture period at 15 days interval. The weight of the shrimp from each grow-out pond was measured using a digital scale (Citizen, Model: CG 1202 L) at a precision of 0.01 g. The shrimp were cultured for 120 days until attains marketable size. To ensure complete harvest, the shrimp were harvested initially by netting and any reaming individuals were harvested by complete draining of the grow-out ponds and hand picking any remaining ones. All shrimps harvested from each pond were weighed and sampled to determine the number of shrimps at harvest.

Growth and productivity performances were evaluated in terms of following:

Average Body Weight (ABW) = Total Biomass (g)/ no. of surviving shrimp

Daily Weight Gain (DWG; g d^{-1}) = (mean final weight (g) – mean initial weight (g))/ rearing duration in days

Specific Growth Rate (SGR; % d^{-1}) = [(ln final weight (g) – ln initial weight (g)) × 100] / rearing duration in days

Feed Conversion Ratio (FCR) = feed consumed (dry wt.)/ live wt. gain (wet wt.)

Survival Rate (SR; %) = (number of shrimp harvested/number of shrimp stocked) × 100

Total Biomass (g) = final ABW x no. of shrimp survivors

Productivity (kg ha^{-1}) = Total Biomass (kg/ha)/ Pond area (ha)

Statistical analysis

All quantitative data obtained from the culture systems were expressed as mean ± Standard Deviation (SD); n=4. Season wise comparisons were made using Welch t-test for normal distributed variances and Mann-Whitney U tests for non-parametric variables. Statistical significance was taken into consideration at $p < 0.05$. Effect sizes (Cohen's d and rank-biseral correlation) were calculated to assess the magnitude of differences.

RESULTS

Across two seasons, the growth performance in *L. vannamei* grow-out ponds assumed the expected rate of a sigmoidal curve typical of penaeid shrimp, where the biomass increased rapidly at initial days of culture (0-75) and gradually slowed at the end of the growth cycle (105-120) until at harvest. Implementations of uniform BMPs in grow-out ponds across two seasons with stocking density (25 m^{-2}), evidence based feeding regimens, continuous aeration and strict biosecurity practices resulted in similar body-weight gain across ponds within each single season. Growth metrics such as ABW, DWG and SGR exhibited very similar trends in the pre and post monsoon seasons, and relative seasonal differences in the indices of somatic growth were very small. Table 1 shows the comprehensive growth data collected at the end of all the grow-out ponds across two seasons.

Table 1: Seasonal variation in growth performance and production metrics, of *Litopenaeus vannamei*: statistical comparison of pre- and post-monsoon periods

Metric		Pre-Monsoon	Post-Monsoon	Test Used	Difference	P Value	Significance	Effect Size
Average Final (g ABW)	Mean Range	33.92 ± 0.51 33.23 to 34.45	33.05 ± 0.24 32.74 to 33.30	Welch t-test	0.87 g ↑	0.0222	*	2.164
DWG (g d^{-1})	Mean Range	0.280 ± 0.005 0.276 – 0.286	0.275 ± 0.015 0.272 – 0.277	Welch t-test	0.005 ↑	0.0213	*	2.188
SGR (% d^{-1})	Mean Range	6.12 ± 0.15 5.89 – 6.21	5.81 ± 0.28 5.59 – 6.18	Mann Whitney U	0.31 ↑	0.0796	NS	-0.812
FCR	Mean Range	1.36 ± 0.08 1.28 – 1.44	1.36 ± 0.01 1.36 – 1.37	Mann Whitney U	0.005 ↓	1.0000	NS	-
SR %	Mean Range	87.74 ± 1.14 86.23 – 88.83	81.97 ± 1.60 80.70 – 84.16	Welch t-test	5.77 ↑	0.0011	**	4.139
Total biomass (kg ha^{-1})	Mean Range	6021.9 ± 124.97 5914.88 – 6192.09	5482.35 ± 88.31 5385.33 – 5575.36	Welch t-test	539.6 ↑	0.0004	***	4.986
Productivity (kg ha^{-1})	Mean Range	7443.64 ± 154.47 7311.35 – 7654.00	6852.94 ± 110.39 6731.66 – 7311.35	Welch t-test	590.7 ↑	0.0008	***	4.400

All values are expressed as Mean ± Standard Deviation (SD); n=4 (number of ponds/season)
↑indicates higher value; ↓indicates lower value
*= p < 0.05, ** = p< 0.01, *** p<0.001, NS indicates not significant = p > 0.05*
ABW: Average Body Weight, DWG: Daily Weight Gain, SGR: Specific Growth Rate, SR: Survival rate, FCR: Feed Conversion Ratio.

Average Body Weight (ABW)

The final ABW values resulted in uniform growth in all ponds across two seasons under same BMPs implementation. From table 1 we can observe the pre and post-monsoon shrimp had final weights ranging from 33.23 to 34.5 g and 32.74 to 33.30 g respectively. With mean average of 33.92 ± 0.51 g (pre-monsoon) and 33.05 ± 0.24 g (post-monsoon) (Fig. 1).

Statistical analysis Welch t-test (t6=3.060, p=0.0222) showed statically significant difference in seasons with a large effect size of Cohen d=2.164. This marginal, yet significant pre-monsoon weight difference (0.87 g difference) does not confirm to the original hypothesis of growth inhibition of the season during the post-monsoon season. This smaller coefficient of variation in the post-monsoon ponds (0.7% vs. 1.5) indicates fewer individuals varying in their growth despite climate change across both seasons, which may indicate greater adaptive stability or equal distribution of resources in low population density.

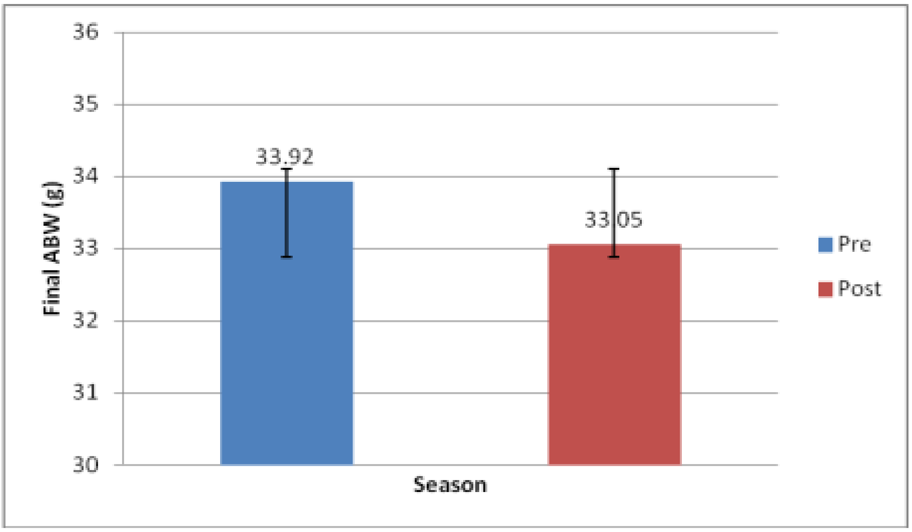

Fig. 1. Variation in Average Final ABW (g) of *L.vannamei* between Pre- and Post-monsoon seasons

Daily Weight Gain (DWG)

The values of DWG were not climatic/season specific. From table 1 we can observe the pre and post-monsoon shrimp had final weights ranging from 0.276 to 0.286 g d^{-1} and 0.272 to 0.277 g d^{-1}respectively, and consistent between ponds proves that the DWG patterns could be reproduced in each season to a high degree. With mean average of 0.280 ± 0.005 g d^{-1} (pre-monsoon) and 0.275 ± 0.015 g d^{-1} (Fig. 2).

Statistical analysis Welch t-test (t6=3.095, p=0.0213, Cohen d=2.188) showed that there was statistical significant marginal difference in pre-monsoon performance. Nevertheless, the applied significance of this difference (0.005 g d^{-1} to 0.06 g d^{-1} in 120 days) is significant in comparison with the final body weight.

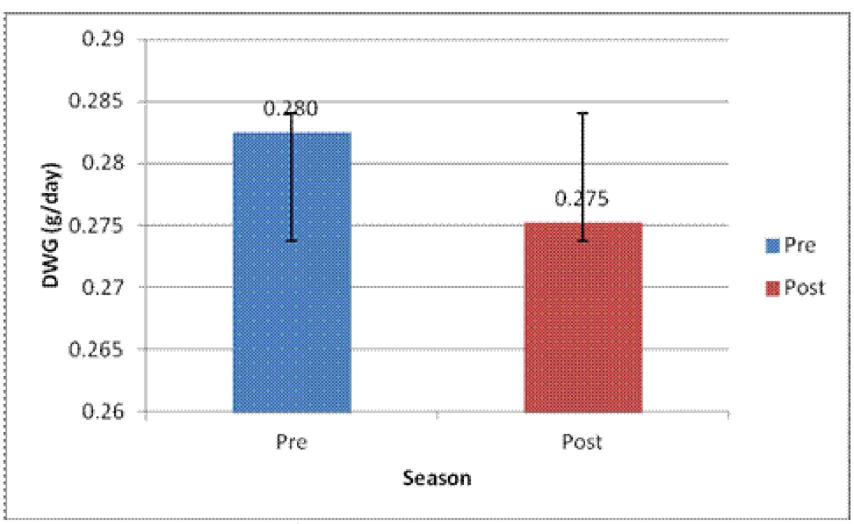

Fig. 2. Variation in Mean DWG (g day^{-1}) of *L.vannamei* between Pre- and Post-monsoon seasons

Specific Growth Rate (SGR)

SGR (% d^{-1}) exhibited limited variation across two seasons and in culture ponds. From table 1 we can observe the pre and post-monsoon shrimp had final SGR ranging from 5.89 to 6.21 g (% d^{-1}) and 5.59 to 6.18 g (% d^{-1}) respectively. With mean 6.12 ± 0.15 g (% d^{-1}) (pre-monsoon) and 5.81 ± 0.028 g (% d^{-1}) (Fig. 3). Statistical analysis Mann-Whitney U-test (U=14.5, p=0.0796) showed no statistically difference between two seasons.

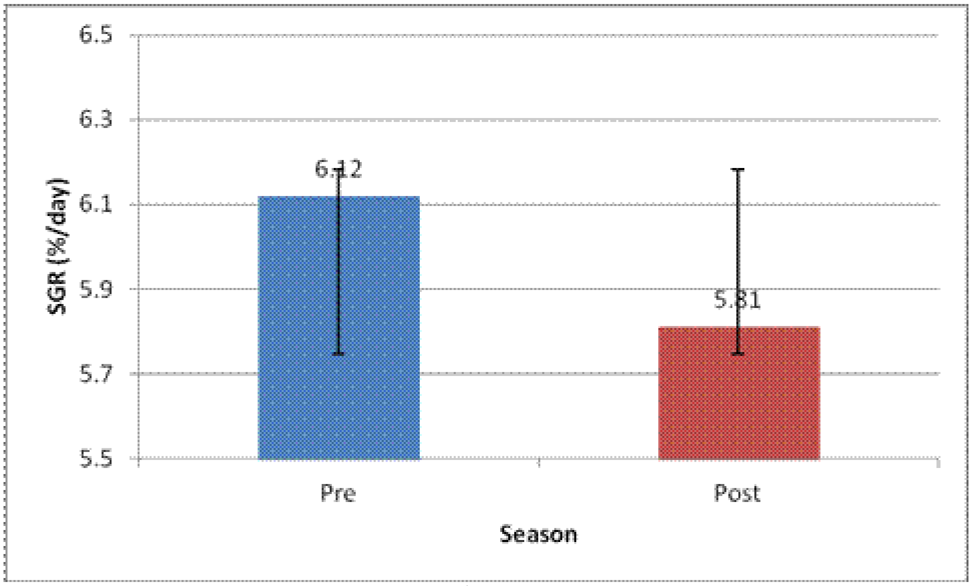

Fig. 3. Variation in Final Mean SGR (% day^{-1}) of *L.vannamei* between Pre- and Post-monsoon seasons

Feed Conversion Ratio (FCR)

Feed ratio kept in the optimum commercial ranges in both seasons and varied with an insignificant difference which ranging from 1.28 to 1.44 in pre-monsoon and 1.36-1.37 in post-monsoon periods, averaging 1.36 ± 0.08 and 1.36 ± 0.01 (Fig. 4)

Statistical analysis Mann-Whitney U-test (U=8.0, p=1.0000) did not show statistically significant difference. FCR in the post-monsoon period was remarkably consistent, implying that there were effective feeding management guidelines regardless of seasonal conditions.

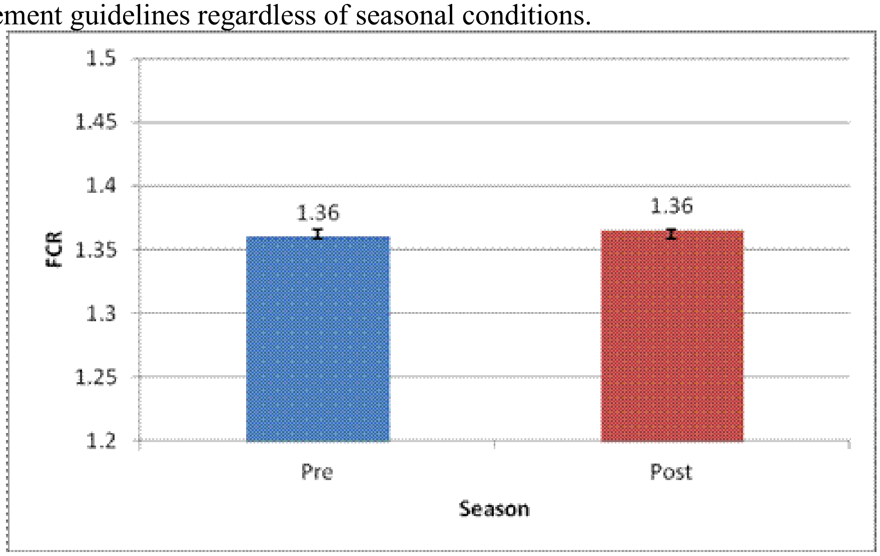

Fig. 4. Variation in Mean FCR of *L.vannamei* between Pre- and Post-monsoon seasons

Survival Rate (%)

The only growth related parameter that had a statistically significant and biologically significant seasonal difference was survival. Unlike growth measures that were similar across seasons, there was strong seasonal adaptability in survival. From table 1 we can observe the pre and post-monsoon shrimp had final survival rate % ranging from 86.23 to 88.83 and 80.70 to 80.84 respectively, With averaging 87.74 ± 1.14 % (pre-monsoon) and 81.97 ± 1.60 % (post-monsoon) (Fig. 5).

Statistical analysis Welch t-test (t6=5.854, p=0.0011, Cohen d=4.139) indicated that a large and very significant seasonal effect was present. The absolute mortality increments (5.77 % decreases during the post-monsoon) is estimation of loss about 11,700 animals per culture pond (of the initial 182,000 to 171,000 animals surviving) over culture period. This disparity was uniform to all four post-monsoon ponds implying great and non-random seasonal mortality.

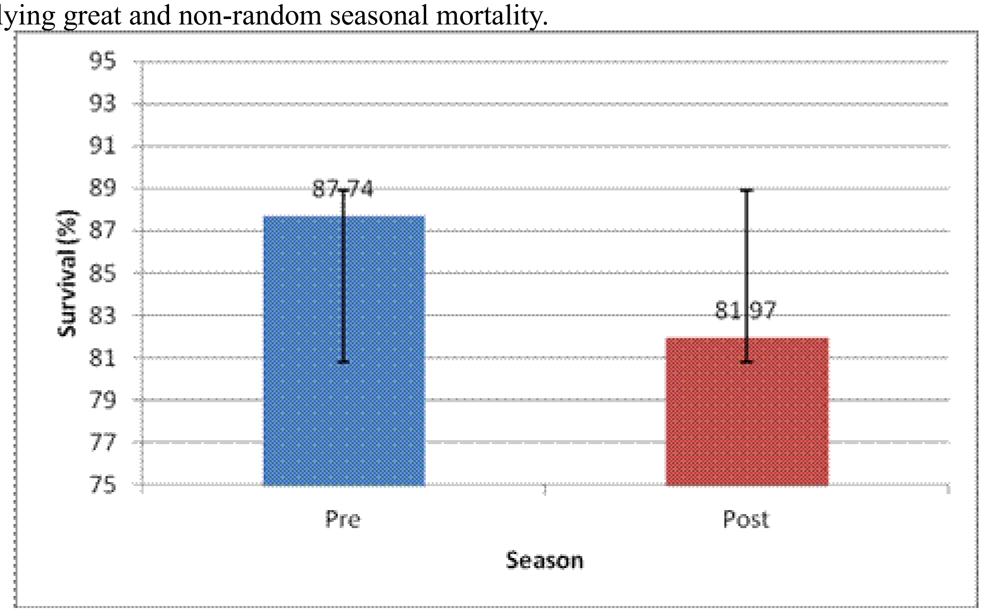

Fig. 5. Variation in Final Mean SR% of *L.vannamei* between Pre- and Post-monsoon seasons

Total Biomass

The expected linear increments on total biomass was directly related to ABW x survival. The two drivers (weight of individual and population density) produced dissimilar production outputs across seasons. From table 1 we can observe the pre and post-monsoon shrimp had Total biomass ranging from 5914.88 to 6192.09 and 5385.33 to 5575.36 respectively, With averaging 6021 ± 124.97 kg (pre-monsoon) and 5482.35 ± 88.31 kg (post-monsoon) (Fig. 6).

Statistical analysis Welch t-test (t6=7.052, p=0.0004, Cohen d=4.986) demonstrated that the seasonal difference was highly significant and the effect size is very large. The pre-monsoon benefit was 539.55 kg/p (8.9% production growth) or 5395 kg ha^{-1} in terms of per-area value.

To test the effect of growth and survival on the difference in biomass, we tested the effect of each parameter by using the formula:

Biomass Change = (ABW Pre – ABW Post) x survival post + ABW Pre x (Survival Pre-Survival Post) substituting empirical values:

- Growth contribution: (33.92 – 33.05) x 181,970 = 157,894 kg
- Survival contribution: 33.92 x (87.74 – 81.97) x (per-pond stock of -180k) = 337,655 kg

A significant part 86 % of the biomass in post-monsoon ponds is due to reduced survivability, only a small fraction 14% of the biomass loss is due to marginal differences in individual growth. This observation is significant in the analysis of seasonal production patterns which post-monsoon productivity difference is a survival driven, rather than a growth difference.

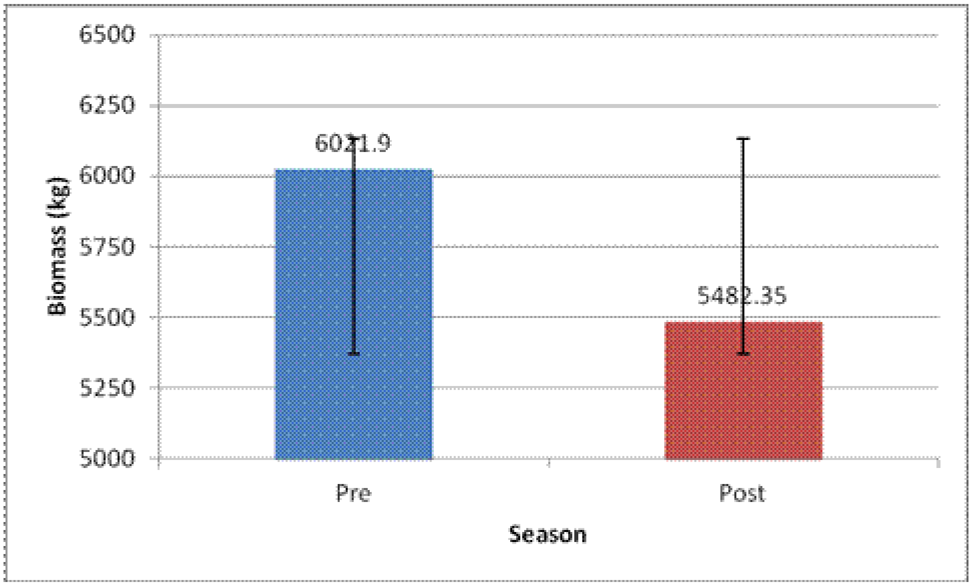

Fig. 6. Variation in Mean Total Biomass (kg pond $^{-1}$) of *L.vannamei* between Pre- and Post-monsoon seasons

Productivity

Productivity is determined as total biomass divided by pond area (0.809 ha/ pond), thus normalizing the results to compare across inter-sites and be able to benchmark against industrial standards. From table 1 the pre-monsoon productivity ranging from 7311.35 to 7654.00 kg ha^{-1} with averaging 7443.64 ± 154.47 kg ha^{-1} to 6852.94 ± 110.39 kg ha^{-1} (Fig.7).

Statistical analysis Welch t-test (t6=6.223, p=0.008, Cohen d=4.400) revealed the presence of a very significant seasonal difference with a massive effect size. The overall productivity difference was 590.70 kg ha^{-1} (7.9% reduction in post-monsoon) which is very significant economic cost to the commercial producers.

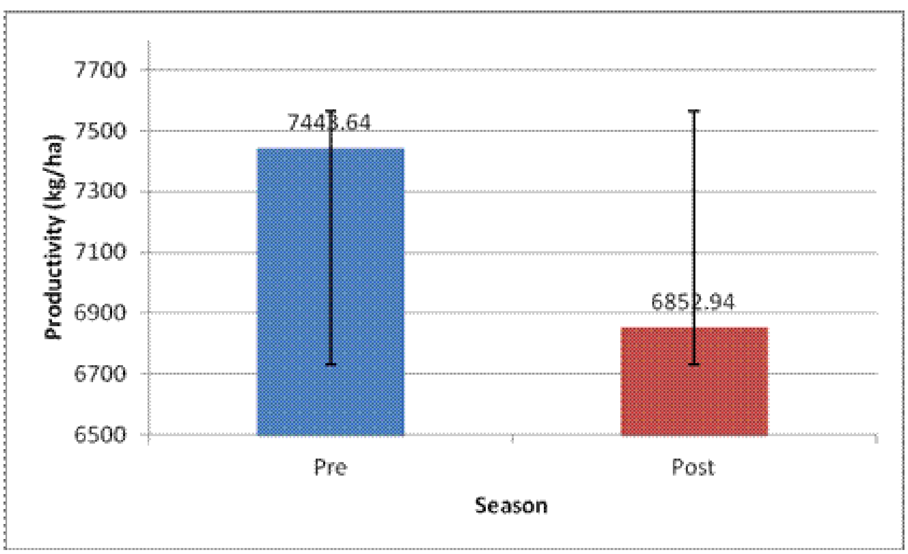

Fig. 7. Variation in Final Mean productivity (kg ha^{-1}) of L.vannamei between Pre- and Post-monsoon seasons

DISCUSSION

BMP-Regulated resilience of somatic growth

The seasonal variation of ABW and DWG was statistically different, however, the absolute difference (0.87 g ABW; 0.005 g d^{-1} DWG) was biologically insignificant. These values are pretty close to the commercial expectations of harvest (30-35 g) and they demonstrate that BMPs ensured ease of access to feed, and metabolic performance across seasons.

The non significant change in SGR also substantiates the observation that the exponential growth was not crippled by the climatic changes in the physiological power of extending such growth. This follows the past publications stating the significance of stable somatic development in *L. vannamei* in an unstable environment by employing strict feeding, aeration, and water-quality management (Aisyah *et al*., 2023; Zhou *et al*., 2020; Huang *et al*., 2020).

Feed Conversion efficiency and seasonal resilience

The seasonal difference in FCR was not significant (1.36) and the seasonal difference in post-monsoon ponds was not significant (SD =0.01). This excellent stability is a measure of efficacy in check-tray feeding, adjustment of the ration based on consumption observed, and standardized progression of the feed size in the prevention of feed wastage, even in high mortality during the post-monsoon. These outcomes are consistent with the previous findings, which optimized feeding strategies reduce the impact of climatic stress on the feed consumption (Haque *et al*., 2025; Hussain *et al*., 2021; Mansour *et al*., 2022).

This shows that the FCR survived under low conditions of survival, which shows that the BMPs actually succeeded in keeping the feed efficiency from fluctuations in real time biomass, which is an important indicator of the climate adaptive management. Likewise, this observation has been made with the accurate feeding, consistent checking, and avoidance of overfeeding during the stressful climatic seasons (Eissa *et al*., 2022).

Survivability

Survival rate was decreasing significantly and statistically significant reduction in the post monsoon season (87.74 to 81.97) which is translated to loss of approximately 11,700 shrimp per pond as compared to growth and feed consumption.

This tendency prevailed in all the post monsoon ponds and as a consequence, the systemic climatic factors and not administrative misalignments.

The penaeid shrimp has been reported to be affected by climatic conditions that define the post-monsoon season causing physiological stress, immunosuppression, and diseases, which include variable salinity, decreased thermal stability and hydrological stress (Adhikari *et al*., 2018; Maulu *et al*., 2021; Abu Samah *et al*., 2021). Survival rate will decreased, as the season changes, *L. vannamei* is more vulnerable to osmotic and thermal shocks despite its adaptability (Ye *et al*., 2023; Ul Hassan *et al*., 2021).

Biomass and Productivity

The biomass and productivity decreased significantly by 539.6 kg $pond^{-1}$ and 590.7 kg ha^{-1}, respectively. These losses indicated that 86 percent of the loss was attributable to a decreased survival but only 14 percent was attributable to individual differences in development.

This determines that the stunted growth performance did not cause the shortages in the production but it was majorly caused by negative population growth. This effect has been observed in the related literature where moderate alterations in survival had a biased effect of total harvestable biomass (Durai *et al*., 2022; Nisar *et al*., 2021).

Improving BMPs to Climate-resilient Aquaculture.

Recent literatures suggest that a number of improvements are recommended to enhance climate resilience including: Strengthened biosecurity and prevention of diseases (Sivaraman *et al*., 2019), Improved salinity buffering as well as aeration (Saraswathy *et al*., 2022), Probiotic and Immunostimulant adaptive feeding supplementation during high-risk periods (Ayiku *et al*., 2020; Eissa *et al*., 2022), Climate based scheduling of the production cycles to avoid overexposure to extreme exposure to post-monsoons. A combination of these factors may render mortality and stabilize production without the demerits of the existing BMP systems.

CONCLUSION

The study showed that the standardized application of BMPs were successful in stabilizing the somatic development of performance and feed efficiency of *Litopenaeus vannamei* in two opposite climatic seasons. The main growth parameters like ABW, DWG and SGR fell in the optimum commercial ranges across two seasons but had slight seasonal variations. Consistent FCR was maintained, survival on the other hand, showed a strong seasonal decrease during the post-monsoon with repercussions in massive losses in biomass and productivity. There is a necessity having additional climatic-adaptive interventions to strengthen BMPs.

ACKNOWLEDGEMENT

The authors wish to thank the farm owners and farm supervisor who supported and allowed to do research work in their culture ponds. Their collaboration during the course of work is exceptional. We also wish to thank the University for providing University Research Fellowship which financially supported to carry this work. The authorities in Acharya Nagarjuna University deserve a special mention because they made the resources and infrastructure available in the Department of Zoology & Aquaculture and this work was fruitful.

REFERENCES

Abu Samah, A., Shaffril, H. A. M., Fadzil, M. F., Ahmad, N., & Idris, K. (2021). A systematic review on adaptation practices in aquaculture towards climate change impacts. *Sustainability,* **13** (20), 11410. *https://doi.org/10.3390/su132011410*

Adhikari, Subhendu & Chaudhari, Ajit & Barlaya, Gangadhar & Rathod, Ramesh & Mandal, R.N. & Ikmail, Sarosh & GS, Saha & De, Himansu & Iyemperumal, Sivaraman & Mahapatra, Abhijit & Sarkar, Subhas & P, Routray & Pillai, Bindu & Sundaray, J.K.. (2018). Adaptation and Mitigation Strategies of Climate Change Impact in Freshwater Aquaculture in some states of India. *Journal of FisheriesSciences.com. https://doi.org/12. 10.21767/1307-234X.1000142.*

Aisyah, Diana & Ramadhani, Ayu & Fattah, Mochammad & Sofiati, Dwi & Anandya, Asyifa. (2023). The Effect of Plankton Abundance And Water Quality on Vanname Shrimp Growth Performance In Intensive System: Pengaruh Kelimpahan Plankton Dan Kualitas Air Terhadap Performa Pertumbuhan Udang Vanname Pada Sistem Budidaya Intensif. Jurnal Lemuru. *https://doi.org/5.173-182. 10.36526/jl.v5i2.2637.*

Arisekar, U., Shakila, R. J., Shalini, R., Jeyasekaran, G., Padmavathy, P., Hari, M. S., & Sudhan, C. (2022). Accumulation potential of heavy metals at different growth stages of Pacific white leg shrimp, *Penaeus vannamei* farmed along the Southeast coast of Peninsular India: A report on ecotoxicology and human health risk assessment. *Environmental Science and Pollution Research, **29***(20), 30245–30257. *https://doi.org/10.1007/s11356-022-20057-9*

Ayiku, S., Shen, J., Tan, B., Dong, X., & Liu, H. (2020). Effects of dietary yeast culture on shrimp growth, immune response, intestinal health and disease resistance against *Vibrio harveyi*. *Fish & Shellfish Immunology, 102*, 286–295. https://doi.org/10.1016/j.fsi.2020.04.036

Belton, B., Bush, S. R., & Little, D. C. (2018). Not just for the wealthy: Rethinking farmed fish consumption in the Global South. *Global Food Security, **16***, 85–92. *https://doi.org/10.1016/j.gfs.2017.10.005*

Boyd, C. E., D'Abramo, L. R., Glencross, B. D., Huyben, D. C., Juarez, L. M., Lockwood, G. S., McNevin, A. A., & Tacon, A. G. J. (2020). Achieving sustainable aquaculture: Historical and current perspectives and future needs and challenges. *Journal of the World Aquaculture Society, **51***(3), 578–633. *https://doi.org/10.1111/jwas.12714*

Coastal Aquaculture Authority. (2024). *Annual report 2023–2024*. Ministry of Fisheries, Animal Husbandry and Dairying, Government of India. Retrieved from *https://www.caa.gov.in/annual_report.html*

Cornejo-Granados, F., Gallardo-Becerra, L., Leonardo-Reza, M., Ochoa-Romo, J. P., & Ochoa-Leyva, A. (2018). A meta-analysis reveals the environmental and host factors shaping the structure and function of the shrimp microbiota. *PeerJ*, *6*, e5382. *https://doi.org/10.7717/peerj.5382*

Das, Manas & Srivastava, Pankaj & Rej, Anirban & Mondal, Liakat & Sharma, Anil. (2014). A framework for assessing vulnerability of inland fisheries to impacts of climate variability in India. Mitigation and Adaptation Strategies for Global Change. *https://doi.org/10.1007/s11027-014-9599-7*

Department of Fisheries, Ministry of Fisheries, Animal Husbandry and Dairying. (2025). *Annual report 2024–25*. New Delhi, India: Government of India. *http://dof.gov.in/sites/default/files/2025-04/AnnualReport2025English.pdf*

Durai, V., Chrispin, C. L., Bharathi, S., Velselvi, R., & Karthy, A. (2022). Factors determining the economic performance of *Litopenaeus vannamei* (whiteleg shrimp) aquaculture in Tamil Nadu, India. *Aquaculture Research,* ***53***(13), 4689–4696. *https://doi.org/10.1111/are.15961*

Eissa, E. H., Ahmed, N. H., El-Badawi, A. A., Munir, M. B., Abd Al-Kareem, O. M., Eissa, M. E. H., Hussien, E. H. M., & Sakr, S. E. (2022). Assessing the influence of the inclusion of *Bacillus subtilis* AQUA-GROW® as feed additive on the growth performance, feed utilization, immunological responses and body composition of the Pacific white shrimp, *Litopenaeus vannamei*. *Aquaculture Research,* ***53***(18), 6606–6615. *https://doi.org/10.1111/are.16129*

Engelhard, G. H., Howes, E. L., Pinnegar, J. K., & Le Quesne, W. J. F. (2022). Assessing the risk of climate change to aquaculture: A national-scale case study for the Sultanate of Oman. *Climate Risk Management, 35*, 100416. *https://doi.org/10.1016/j.crm.2022.100416*

Fan, L., & Li, Q. X. (2019). Characteristics of intestinal microbiota in the Pacific white shrimp *Litopenaeus vannamei* differing growth performances in the marine cultured environment. *Aquaculture, 505*, 450–461. *https://doi.org/10.1016/j.aquaculture.2019.02.075*

Food and Agriculture Organization of the United Nations (FAO), (2020). *The state of food and agriculture 2020: Overcoming water challenges in agriculture* (1st ed.). FAO. *https://doi.org/10.4060/cb1447en*

Haque, A. B. M. M., Khan, M. A., Hossain, M. M., Hossain, M. E., Nahiduzzaman, M., & Islam, M. S. (2025). Improved aquaculture management practices and its impact on small-scale rural aquaculture farmers in Bangladesh. *Aquaculture, 594*, 741459. *https://doi.org/10.1016/j.aquaculture.2024.741459*

Huang, X., Du, S., Zhang, H., Chen, C., Xiao, G., Huang, L., & Zhang, D. (2020). Temporal patterns of bacterial communities in shrimp (*Litopenaeus vannamei*) culture systems loaded with oyster shells. *Aquaculture, 526*, 735424. *https://doi.org/10.1016/j.aquaculture.2020.735424*

Hussain, A. S., Davi, A., Mohammad, D. A., Sallam, W. S., & Shoukry, N. M. (2021). Effects of culturing the Pacific white shrimp *Penaeus vannamei* in "biofloc" vs "synbiotic" systems on the growth and immune system. *Aquaculture, 542*, 736905. *https://doi.org/10.1016/j.aquaculture.2021.736905*

Intergovernmental Panel on Climate Change (IPCC). (2018). *Global warming of 1.5°C: An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. IPCC. *https://www.ipcc.ch/sr15/*

Jagadeesh, T., Anusha, M., Ganesh, G., & Mohan, M. (2020). Best management techniques in shrimp culture. *Agriallis,* ***4***(10).

Jarh, H. P., Dana, S. S., Mondal, A. H., & Ray (Sarkar), M. (2024). Adoption behaviour of fish farmers towards better management practices (BMPs) of seabass farming. *Indian Journal of Extension Education,* ***60***(3), 12–17. *https://doi.org/10.48165/IJEE.2024.60303*

Joffre, O. M., Poortvliet, P. M., & Klerkx, L. (2019). To cluster or not to cluster farmers? Influences on network interactions, risk perceptions, and adoption of aquaculture practices. *Agricultural Systems, 173*, 151–160. *https://doi.org/10.1016/j.agsy.2019.02.011*

Kumaran, M., Anand, P. R., Kumar, J. A., Muralidhar, M., Vasagam, K. P. K., & Vijayan, K. K. (2021). Assessment of perceived farming risks, communication of risk management practices, and evaluation of their efficiency in Pacific white shrimp (*Penaeus vannamei*) farming—A survey-based cross-sectional study. *Aquaculture International, **29***(6), 2713–2730. *https://doi.org/10.1007/s10499-021-00775*

Kumaran, M., Ravisankar, T., Anand, P. R., Vimala, D. D., & Balasubramanian, C. P. (2017). Knowledge level of shrimp farmers on better management practices (BMPs) of *Penaeus vannamei* farming: A comparative assessment of east and west coasts of India. *Indian Journal of Fisheries, **64***(3). *https://doi.org/10.21077/ijf.2017.64.3.66723-13*

Lalramchhani, C., Panigrahi, A., Anand, P. S. S., Das, S., Ghoshal, T. K., Ambasankar, K., & Balasubramanian, C. P. (2020). Effect of varying levels of dietary protein on the growth performances of Indian white shrimp *Penaeus indicus* (H. Milne Edwards). *Aquaculture, 519*, 734736. *https://doi.org/10.1016/j.aquaculture.2019.734736*

Macusi, E. D., Albarido, N. A., Clapano, M. B., & Santos, M. D. (2022). Vulnerability assessment of Pacific whiteleg shrimp (*Penaeus vannamei*) farms and vendors in Davao, Philippines using FishVool. *Sustainability, **14***(8), Article 4541. *https://doi.org/10.3390/su14084541*

Mansour, A. T., Ashour, M., Abbas, E. M., Alsaqufi, A. S., Kelany, M. S., El-Sawy, M. A., & Sharawy, Z. Z. (2022). Growth performance, immune-related and antioxidant genes expression, and gut bacterial abundance of Pacific white leg shrimp, *Litopenaeus vannamei*, dietary supplemented with natural astaxanthin. *Frontiers in Physiology, 13*, 874172. *https://doi.org/10.3389/fphys.2022.874172*

Marine Products Export Development Authority (MPEDA). (2023). *Better management practices – MPEDA. https://mpeda.gov.in/?page_id=728*

Marine Products Export Development Authority. (2024). *Annual report 2023–24*. Kochi, India: *MPEDA. https://mpeda.gov.in/wp-content/uploads/2020/12/Annual_Report_2023_24.pdf*

Maulu, S., Hasimuna, O. J., Haambiya, L. H., Monde, C., Musuka, C. G., Makorwa, T. H., Munganga, B. P., Phiri, K. J., & Nsekanabo, J. D. (2021). Climate change effects on aquaculture production: Sustainability implications, mitigation, and adaptations. *Frontiers in Sustainable Food Systems, 5, 609097. https://doi.org/10.3389/fsufs.2021.609097*

Mirbakhsh, M., Ghaednia, B., Zorriehzahra, M. J., Esmaeili, F., & Faggio, C. (2023). Dietary mixed and sprayed probiotic improves growth performance and digestive enzymes of juvenile whiteleg shrimp (*Litopenaeus vannamei*, Boone, 1931). *Journal of Applied Aquaculture, **35***(3), 823–836. *https://doi.org/10.1080/10454438.2022.2032528*

Nisar, U., Zhang, H., Navghan, M., Zhu, Y., & Mu, Y. (2021). Comparative analysis of profitability and resource use efficiency between *Penaeus monodon* and *Litopenaeus vannamei* in India. *PLOS ONE, **16***(5), e0250727. *https://doi.org/10.1371/journal.pone.0250727*

Notohamijoyo, A. (2023). *Reaktualisasi poros maritim*. Kubuku. *https://kubuku.id/detail/reaktualisasi-poros-maritim/63044*

Pashudhan Praharee, T. (2020, August 9). General good management practices in fish farming. *Pashudhan Praharee | Pet Care Blog*. *https://www.pashudhanpraharee.com/general-good-management-practices-in-fish-farming/*

Phan, T. C., Nguyen, T. K. L., Pham, T. T. N., Truong, Q. P., & Huynh, T. G. (2023). Effects of garlic-supplemented diet on the growth and survival of the whiteleg shrimp (*Litopenaeus vannamei*). *Livestock Research for Rural Development, **35***(2). *http://www.lrrd.org/lrrd35/2/3520tu.html*

Phillips, M. J., & Subasinghe, R. P. (2006). FAO, NACA, UNEP/GPA, WB, and WWF Consortium on Shrimp Farming and the Environment receive the Green Award for its International Principles for

Responsible Shrimp Farming [Conference presentation]. Paper presented at the Third Session of the FAO Committee on Fisheries Sub-Committee on Aquaculture, New Delhi, India.

Putra, D. F., Trisyahdar, T. N., Dewiyanti, I., & Muhammadar, A. A. (2018). Effect of enhanced *Artemia* with gamat emulsion on growth performance and survival rate of white shrimp *Litopenaeus vannamei* larvae. *IOP Conference Series: Earth and Environmental Science, 216*, 012005. *https://doi.org/10.1088/1755-1315/216/1/012005*

Rao, D. V., Borana, K., & Shrivastava, P. (2022). *Litopenaeus vannamei* (whiteleg shrimp) farming in Indian inland saline ecosystem. *International Journal of Fauna and Biological Studies,* ***9***(3), 68–72.

Ratti, S. V., & Kunda, S. K. (2025). Effects of seasonal variation and better management practices (BMPs) on water quality in *Litopenaeus vannamei* grow-out ponds. *Uttar Pradesh Journal of Zoology,* ***46***(21), 44–57. *https://doi.org/10.56557/upjoz/2025/v46i215328*

Ren, S., Prentis, P., Mather, P. B., Li, Y., Tang, B., & Hurwood, D. A. (2020). Genetic parameters for growth and survival traits in a base population of Pacific white shrimp (*Litopenaeus vannamei*) developed from domesticated strains in China. *Aquaculture, 523*, 735148. *https://doi.org/10.1016/j.aquaculture.2020.735148*

Richardson, A., Dantas-Lima, J., Lefranc, M., & Walraven, M. (2021). Effect of a black soldier fly ingredient on the growth performance and disease resistance of juvenile Pacific white shrimp (*Litopenaeus vannamei*). *Animals,* ***11***(5), 1450. *https://doi.org/10.3390/ani11051450*

Saraswathy, R., Muralidhar, M., Thiagarajan, R., Panigrahi, A., Suvana, S., Kumararaja, P., Katneni, V. K., & Nagavel, A. (2022). Effect of lined and earthen farming practices on pond health in whiteleg shrimp, *Penaeus vannamei* culture. *Aquaculture Research,* ***53***(16), 5606–5617. *https://doi.org/10.1111/are.16042*

Sivaraman, I., Krishnan, M., & Radhakrishnan, K. (2019). Better management practices for sustainable small-scale shrimp farming. *Journal of Cleaner Production, 214*, 559–572. *https://doi.org/10.1016/j.jclepro.2018.12.172*

Suwoyo, H. S., & Hendrajat, E. A. (2021). High density aquaculture of white shrimp (*Litopenaeus vannamei*) in controlled tank. *IOP Conference Series: Earth and Environmental Science, 777*(1), 012022. *https://doi.org/10.1088/1755-1315/777/1/012022*

Swami Durai, S. K., & Shamili, M. D. (2022). Smart farming using machine learning and deep learning techniques. *Decision Analytics Journal, 3*, 100041. *https://doi.org/10.1016/j.dajour.2022.100041*

Ul Hassan, H., Gabol, K., Wattoo, J., Chatta, A. M., Ali, Q. M., Mahmood, K., Hussain, M., Abro, N. A., Attaullah, M., Rahman, S. U., Rashid, A., Rahman, M. A., & Hossain, M. Y. (2021). First Pacific white shrimp, *Litopenaeus vannamei* (Boone, 1931) culture in Pakistan: Evaluation of optimum salinity level for the growth performance and survival in the hypo saline and hyper saline condition under pond ecosystem. *The Journal of Animal and Plant Sciences,* ***31***(5), 1492–1500. *https://doi.org/10.36899/JAPS.2021.5.0351*

Yassien, M. H., Mohamed, M., & Ashry, O. A. (2021). Effect of bioflocs on growth performance and survival of whiteleg shrimp *Litopenaeus vannamei* raised in zero-water exchange culture tanks. *Egyptian Journal of Aquatic Biology and Fisheries,* ***25***(2), 645–657. *https://doi.org/10.21608/ejabf.2021.69110.2144*

Ye, Y., Zhu, B., Zhang, J., Yang, Y., Tian, J., Xu, W., Du, X., Huang, Y., Li, Y., & Zhao, Y. (2023). Comparison of growth performance and biochemical components between low-salinity-tolerant hybrid and normal variety of Pacific white shrimp (*Penaeus vannamei*). *Animals,* ***13***(18), 2837. *https://doi.org/10.3390/ani13182837*

Zacharia, P. U., Gopalakrishnan, A., George, G., Muralidhar, M., & Vijayan, K. K. (2016). Climate change impact on coastal fisheries and aquaculture in the SAARC region: Country paper – India. Paper presented at the SAARC Agriculture Centre Video Conference on "Climate Change Impact on Coastal Fisheries and Aquaculture," SAARC Member Countries.

Zhou, L., Li, H., Qin, J. G., Wang, X., Chen, L., Xu, C., & Li, E. (2020). Dietary prebiotic inulin benefits on growth performance, antioxidant capacity, immune response and intestinal microbiota in Pacific white shrimp (*Litopenaeus vannamei*) at low salinity. *Aquaculture, 518*, 734847. *https://doi.org/10.1016/j.aquaculture.2019.734847*